POSSIBLE EFFECTS OF ELECTRICALLY CHARGED PARTICLES IN IO'S VOLCANIC PLUMES.

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On Earth, plumes from explosive volcanic eruptions often display atmospheric electrical effects such as lightning and its associated thunder. These phenomena demonstrate that eruption plumes can be highly electrically charged and that a charge separation mechanism must be operating. There is no reason why electrical charging in volcanic environments should be constrained to Earth and plumes on Io may also be charged. With Io's low gravity and lack of atmosphere, any electrical charge on ballistic particles could become an important factor influencing their trajectories in a magnetic field.

The pertubation of the Earth's natural atmospheric electrical field due to the presence of volcanic plumes has already been studied by a variety of techniques. Near the ground beneath plumes, the potential gradient is commonly measured to be in the order of kilovolts per metre. The charge to mass ratio of falling ash has also been measured with values of $\pm 10^{-4}$ C/kg recorded [1]. The results appear to indicate that ash is charged close to the limiting value in Earth's atmosphere. Above this limit, the high surface charge density on an ash particle will cause discharge through the air until the limiting value is reached.

Many theories have been advanced to explain the charge generation and separation. The most recent work [2] suggests that ash in plumes has a net negative charge, a net positive charge residing in the volcanic gases or on very fine ash. Charge separation then occurs due to the gravitational separation of the gases and the ash. The mechanism of charge generation in volcanic plumes is not known. However, a strong possibility is fracto-emission during magma fragmentation. Fracto-emission is the release of particles and electromagnetic radiation during and shortly after the fracture of a material [3]. The process often releases charged particles (electrons and ions) and leaves the fractured material electrically charged. Thus it is thought that the charging may be an effect of the extensive brittle fracture of magma.

Voyager results from Io showed many asymmetric plumes [4] and with recent results from Galileo suggesting that Io has a magnetic field, it is possible that one effect that may cause asymmetry in plumes is the interaction of charged volcanic particles with the magnetic field. For environments where there is no (or very little) atmosphere, the charges held on particles can be much larger than when an atmosphere is present. If this is the case for eruptions on Io, then the interaction of the moving charge with a magnetic field may appreciably alter the trajectories of ballistic particles.

In a very simple simulation, the effect a magnetic field would have on the landing positions of ejected volcanic particles can be seen (Fig. 1). The figure shows the landing positions of particles launched in increments of 5 (up to 45) degrees from the vertical, and at intervals of 12.5 degrees of azimuth. A steady, uniform magnetic field is orientated horizontally in the direction of the x axis. The effect of the electromagnetic interaction on the equations of motion for particles can be represented by the parameter Bq/m (magnetic flux density x charge per unit mass). In Fig. 1a. Bq/m is essentially zero, and the symmetrical distribution of particles following "normal" ballistic trajectories can be seen. Fig. 1b. shows the simulation run with Bq/m = 0.0001 TC/kg and gives only a very slight pertubation from the symmetric pattern. With Bq/m = 0.001 TC/kg considerable asymmetry is visible.
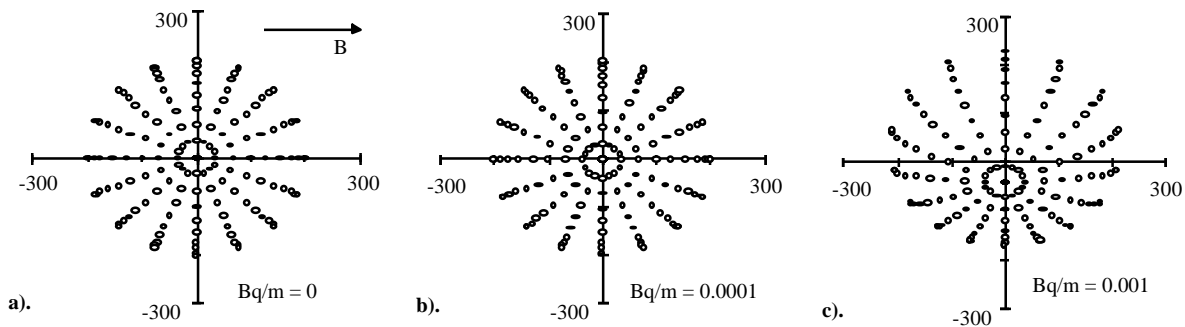

Fig. 1. Landing positions of charged particles launched from a cylindrical vent located at the origin. Particles launched at 600m/s in increments of 5 degrees from the vertical (up to 45 degrees), and intervals of 12.5 degrees of azimuth. A magnetic field of flux density B, is orientated horizontally in the direction of the x axis. Distances in km, Bq/m in TC/kg.

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Note that any effect of the plume on the magnetic field is neglected and that the magnetic flux density does not vary with height. Only particles of one value (and sign) of charge per unit mass are considered at one time; a range of values in one plume would be more realistic, however the long duration of the eruptions on Io could ensure that any asymmetry in the deposits are removed by the continually changing direction of the magnetic field.

On Earth, fragmentation of basaltic magma is predominantly not a brittle process, but on Io, where up to 25% of the eruptive mass may be entrained as cold volatiles before eruption, this rapid chilling of the magma may make brittle fragmentation much more common. Despite Io's low temperature and lack of atmosphere, magma fragmentation is likely to occur at similar pressures to terrestrial explosive eruptions. Thus it can be argued that surface charge densities on particles are unlikely to grossly exceed those found on Earth. In this case, to achieve Bq/m near 0.001 TC/kg, unrealistic magnetic flux densities of over 1 T would be required.

If the charge on solid ejecta gives only a small charge per unit mass, and an equal and opposite charge is assumed to reside in the volatile phases, on Earth their charge per unit mass will be greater because they represent only a small mass fraction of the ejecta. However, with such large proportions of volatiles in eruptions on Io, this effect will be smaller than on the Earth. Even so, it may be that the particles for which Bq/m is largest are solid flakes of condensed S or SO_2.

Electrical processes in volcanic plumes are not sufficiently understood for a charge per unit mass to be estimated reliably for Io's plumes. However, even if the charge per unit mass or strength of the magnetic field are not sufficient to perturb particle trajectories significantly, the effect could cause increased particle-particle interactions as the paths of oppositely charged particles cross. This, along with electrostatic attraction, may cause aggregation - a factor that has not yet been allowed for in any of the plume modeling for Io.

References:

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